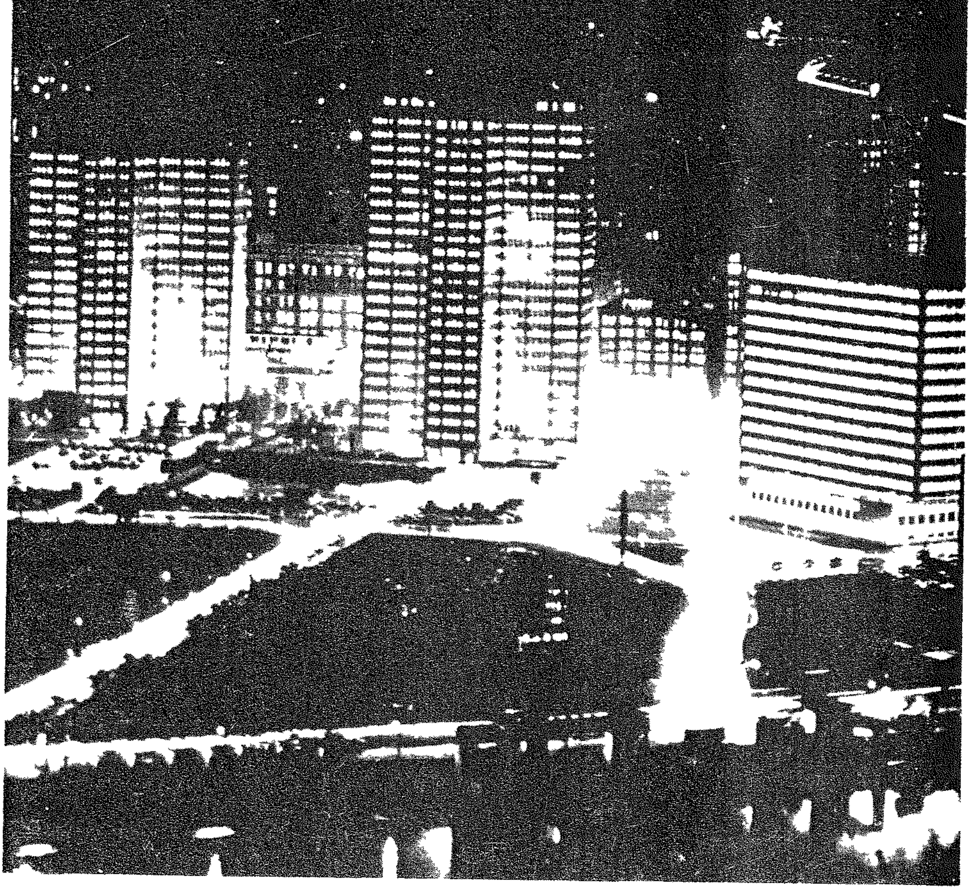
ATOMIC ENERGY and your world

by Samuel Glasstone and
S. Joe Thomas



Nuclear energy is playing a vital role in the life of every man, woman, and child in the United States today. In the years ahead it will affect increasingly all the peoples of the earth. It is essential that all Americans gain an understanding of this vital force if they are to discharge thoughtfully their responsibilities as citizens and if they are to realize fully the myriad benefits that nuclear energy offers them.

The United States Atomic Energy Commission provides this booklet to help you achieve such understanding.

The Cover

The lights of downtown Pittsburgh. The Shippingport Atomic Power Station provides electricity for the homes and factories of the greater Pittsburgh area The station began operation in 1957

THE AUTHORS

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Samuel Glasstone–Ph.D. (1922), D.Sc. (1926) University of London, in Physical Chemistry–holds a preeminent position as a lucid expositor of scientific subject matter. He has written 34 books, sometimes with the cooperation of other scientists. In 1959 the American Society of Mechanical Engineers awarded him the Worcester Reed Warner Medal in recognition of his "outstanding contribution to permanent engineering literature in (his) writings on atomic energy". In 1968 he received the Arthur Holly Compton Award from the American Nuclear Society for "his distinguished contributions to nuclear science and engineering education".

Dr. Glasstone's best known book in the nuclear field is *Sourcebook on Atomic Energy;* first published in 1950 and revised in 1958 and 1967, it is still a best seller. He has also written for scientists and engineers about reactor theory, nuclear engineering, nuclear weapons, and controlled thermonuclear research, as well as various aspects of physical chemistry.

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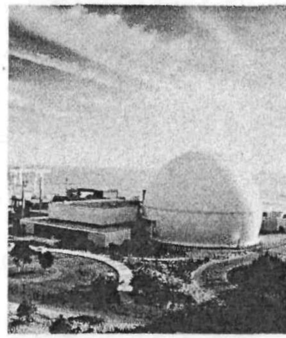
WHY IS IT IMPORTANT TO KNOW ABOUT THE ATOM?

We hear a great deal about atomic bombs and the damage they can do. But we hear very little about the peaceful uses of the atom. Even the atomic bomb can be used for peaceful purposes. These uses are important now, and, in the long run, will be very important to you and the other inhabitants of the earth.

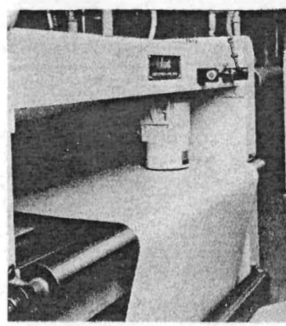
To understand the many uses of the atom we must look a little more closely into its nature.

Did you know that, in many parts of the United States and in several other countries, electricity for homes and factories is provided by atomic power?



Did you know that certain atoms are used in medicine to diagnose and cure disease?

Did you know that atoms are used to solve problems in industry?



Did you know that atomic energy is used to propel submarines?

WHAT IS MATTER?

Look around you. What do you see? Houses, trees, furniture, clothing, water, other people. There are also things we can't see but know are there—air, for example. How do we know? We breathe it; we feel it as wind.

There are many, many thousands of things. Some are solid, such as concrete, bricks, and wood. Some are liquid, such as water, milk, and soft drinks. And some are gases, such as air, exhaust from a car, and carbon dioxide, which makes the bubbles in soft drinks.

Air is one of the things we can't see but know is there. How do we know? We breathe it; we feel it as wind.

WHAT ARE ELEMENTS?

Everything in our solar system is made up of only 90 distinctly different materials. These 90 materials are called *elements.* Some of these elements are gold, silver, and copper.

Can you name some others?

Although there are only 90 natural elements on the earth, 15 others have been produced by scientists in the laboratory. Consequently, 105 elements are now known. Because scientists are continually trying to make new elements, this number may well increase as time goes on. But it is very unlikely that more than 90 elements will be found to occur naturally on earth.

In one way an element can be compared to a letter in the alphabet. The English alphabet has only 26 letters, but with them we can form hundreds of thousands of words. All these words are different and usually represent different things. No single word contains all 26 letters. Some contain two letters, others three, and so on. The addition of a letter to a word can sometimes change its meaning completely. For example, if we add the letter e to man, we can make mane or mean, or by adding y we have many.

Some materials consist of a single element: mercury, iron, tin, etc. Other materials, such as salt, water, and sugar, contain two, three, or more elements held closely together, like a word. Sugar contains three elements—carbon, hydrogen, and oxygen—in certain

definite proportions. Wood is also made up of these three elements but in different proportions. These combinations are called *compounds* and are quite different from the elements of which they are made, just as a word is different from its letters. There can also be mixtures of elements or compounds. These could be compared to sentences.

EVERYTHING IS MADE UP OF ATOMS

About 2500 years ago Greek philosophers, who were the learned men of their time, thought a great deal about the nature of matter. Some wondered what would happen if a piece of matter—for example, iron—was split into smaller and smaller pieces. Suppose we divided it into halves, then each half was divided into quarters, quarters into eighths, and so on. Could this division go on forever? Or would we eventually come to a piece so very small that it could not be split further?

Democritus

Some Greek thinkers argued in favor of the first way, others favored the second. The Greek philosopher Democritus favored the second way. He thought that all material things were made up of small indivisible particles. He called these particles "atoma", which means something that cannot be cut. It is from this Greek word that the English word *atom* is derived.

The idea of atoms was not accepted by everyone. In fact, for more than 1500 years it was ignored almost completely. Then, about 300 years ago, some famous scientists like Galileo Galilei (1564-1642) in Italy, Isaac Newton (1642-1727) in England, and others, started to think about atoms again. They concluded that all matter was made up of individual particles which could not be divided.

The writings of these men concerning atoms did not have much effect during their

lifetimes, perhaps because there was so much that was not really understood. A great deal of study was still needed before the idea of atoms could be generally accepted.

In 1803, John Dalton, an English schoolteacher, expressed his ideas about atoms. He described the experiments he had made, and other scientists gradually accepted the view that all matter was made up of indivisible atoms.

We will say more later about what Dalton did, but first let us review what we know.

John Dalton

All matter on earth is made up of 90 different elements. If we take a piece of any element, for example, gold, and imagine it to be split into smaller and smaller pieces, the smallest piece we would eventually obtain—one which could not be split further— would be an atom of gold. Any one atom of the element gold is the same as any other atom of that element. Thus, the atom carries the distinct properties of the particular element. Some properties of gold are that it is a soft yellow metal, and it remains bright and shiny for a long time.

Suppose we take a piece of the element aluminum and break that up. Eventually we would obtain atoms of aluminum. The atoms of aluminum would, however, be different from the atoms of gold.

Every element has its own kind of atoms, which are identical, but they are different from the atoms of another element.

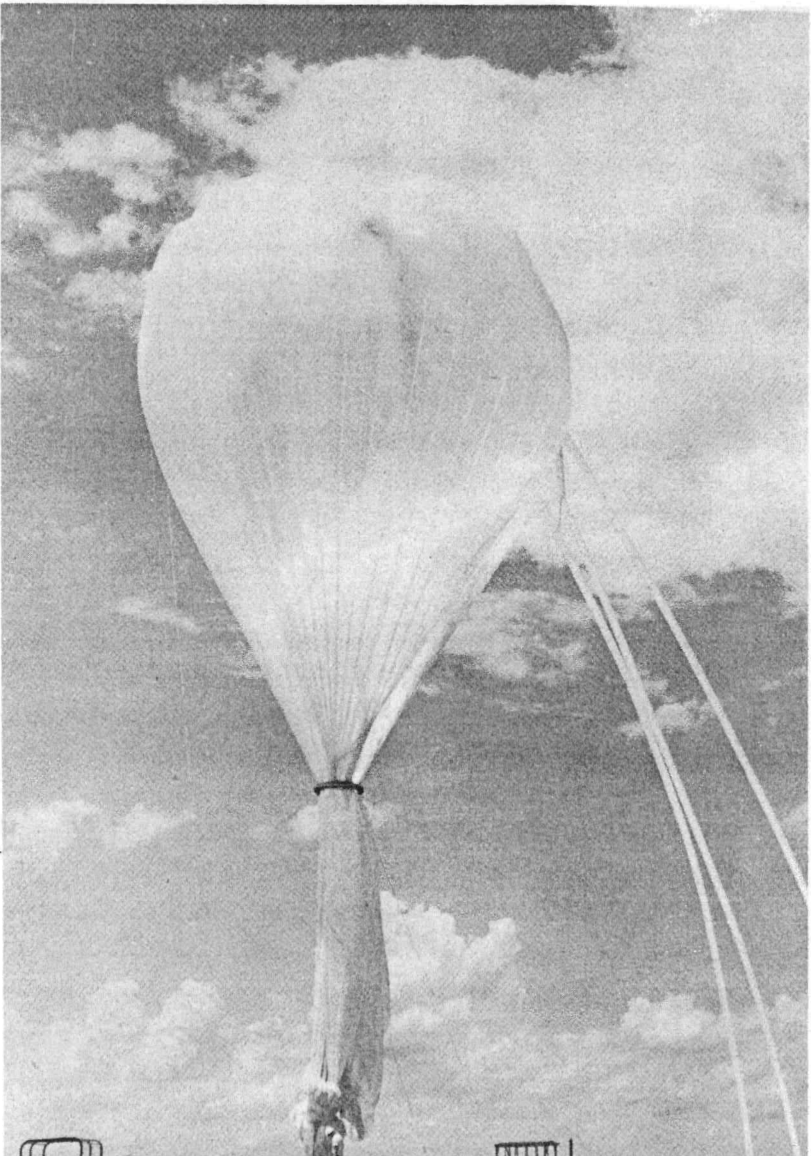
WHAT ARE ATOMIC WEIGHTS?

Single atoms are so small that only in a few cases have they been made visible by the use of special microscopes. The smallest speck of dust contains many millions of atoms, and so it is impossible to weigh a single atom. One of the important things John Dalton did was to show how the weight of an atom of one element could be compared with the weight of an atom of another element.

The lightest atom known is a hydrogen atom, and, for convenience, this atom was given the weight of 1 atomic unit. The weight of an atom of any other element compared with that of hydrogen is called the *atomic weight* of that element. For example, an atom of gold is 197 times heavier than an atom of hydrogen. The atomic weight of the element gold is thus 197.

The atomic weights of some of the better known elements are listed below.

You will notice that the atomic weights in the table are given as whole numbers. This is not exactly true because atomic weights actually have decimals after the whole numbers. For example, the atomic weight of hydrogen is 1.008 (rather than 1) and the atomic weight of mercury is 200.6 (rather than 201). There are several reasons why this is so. One is that atomic weights are no longer given in comparison with hydrogen. Another will be mentioned on page 27. But in this booklet, in order to keep things as simple as



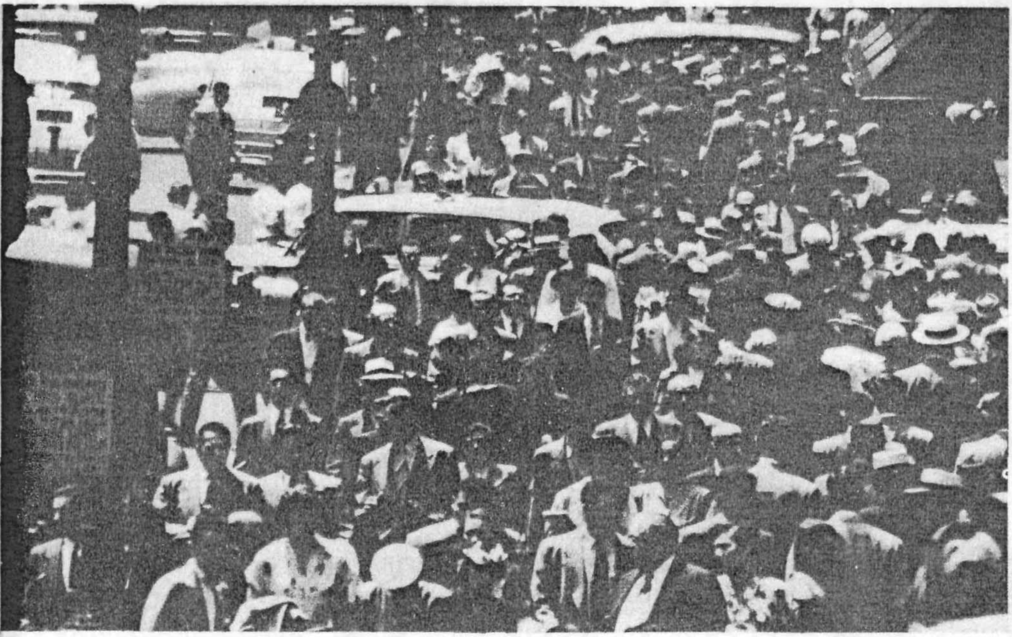
Helium has an atomic weight of 4. Above, a weather balloon is inflated with helium, which is used because it is lighter than air.

possible, we will use whole numbers for atomic weights.

Weight is the *force* of gravity pulling on an object. *Mass* is the *amount* of material in an object. Astronauts out in space have the same mass as they have on earth, but they have no weight. Instead of using the word weight when discussing atoms, we will often use the term mass.

TABLE OF ATOMIC WEIGHTS OF SOME IMPORTANT ELEMENTS

Element	Atomic weight
Aluminum	27
Calcium	40
Carbon	12
Hydrogen	1
Iron	56
Mercury	201
Nitrogen	14
Oxygen	16
Silver	108
Sulfur	32



If all the people in the United States were the size of hydrogen atoms and were placed in a single file, they would form a line less than 1 inch long.

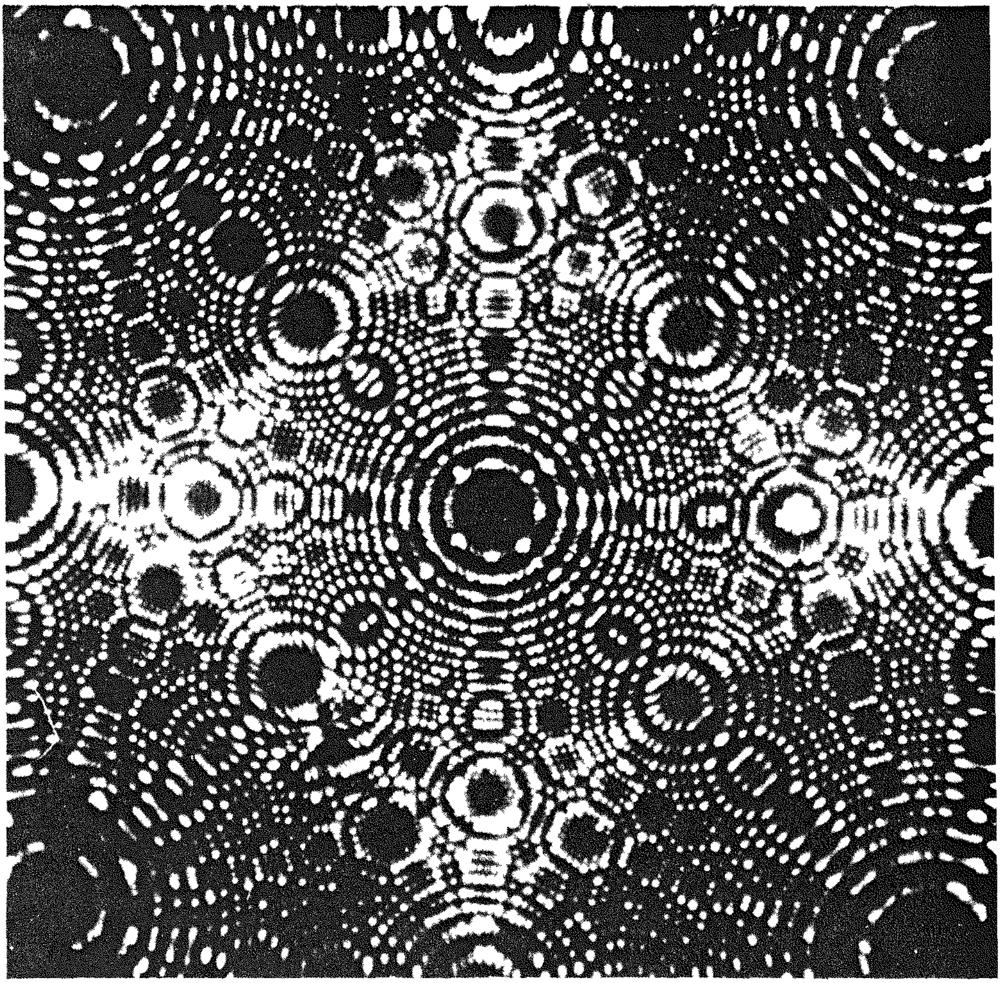
HOW BIG ARE ATOMS?

Atoms of different elements have different masses and also different sizes. How big (or small) is an atom?

Imagine atoms of hydrogen placed alongside one another to form a line 1 inch long. There would then be about 250 million atoms in this line. If all the people in the United States—over 200 million men, women, and children—were the size of hydrogen atoms and were placed in single file, they would form a line less than 1 inch long. The heavier atoms, that is, those with high atomic weights (or atomic masses), are somewhat larger than hydrogen atoms. But even with the largest

atoms, it would still require over 100 million, side by side, to make a line 1 inch long.

Of course, in measuring size, it is not possible to put a ruler against an atom (or even several atoms) to see how big one is. But scientists have invented ways of determining both the sizes and masses of single atoms.



Field-ion micrograph of a crystal. Each tiny dot is a single atom.

SPLITTING THE ATOM

For many years people thought that atoms could not be split. Several discoveries, made about 1900, led to a change in the old ideas. We now know that atoms can be split. But when this is done, the parts of the atom no longer have the element's properties. Think of a brick wall. We can take it apart, but then it is no longer a wall.

The parts (or building blocks) are the same for the atoms of all elements. We know that *three* different kinds of building blocks are found in all atoms. These building blocks are called *elementary particles.*

There is one exception to the rule that all atoms are made up of three kinds of particles: The common form of hydrogen, the lightest of all atoms, contains only *two* particles.

THREE KINDS OF ELEMENTARY PARTICLES

How do atoms of various elements differ from each other? They differ in the *numbers* of the three kinds of particles that each contains. These particles are called *electrons, protons,* and *neutrons.* The number of electrons is always the same as the number of protons, but the number of neutrons can be different.

What led us to believe that all atoms, except hydrogen, are made up of three different kinds of particles? Many scientists in several countries carried out large numbers of experiments in their laboratories, and from these experiments some clear ideas gradually emerged. The road was a long one, but after many twists and turns and deadends, a very satisfactory theory was formed.

Electrons and Protons

One scientist who made important studies at the end of the 19th century was J. J. Thomson in England. He reached the conclusion that all atoms contained an elementary particle called an *electron.* It is the lightest known particle in an atom—so light that it takes 1837 electrons to weigh as much as an atom of hydrogen.

There is something else that is special about an electron besides its very light mass: It has a negative charge of electricity. A negative charge of electricity balances a posi-

tive charge of electricity. Negative charges are sometimes called minus charges and positive charges are sometimes called plus charges.

All things in nature usually have an equal amount of each kind of charge and are balanced electrically (or electrically neutral).

The atom must therefore contain particles with a positive electric charge to balance the negative charge of the electrons. The elementary particles in the atom that carry a positive charge are the *protons.*

Now we can see why the number of electrons must be the same as the number of protons in the atom. The total negative

J. J. Thomson in his laboratory. On the right are early X-ray pictures.

electric charge carried by the electrons must balance the total positive charge carried by the protons if the atom is to be electrically neutral.

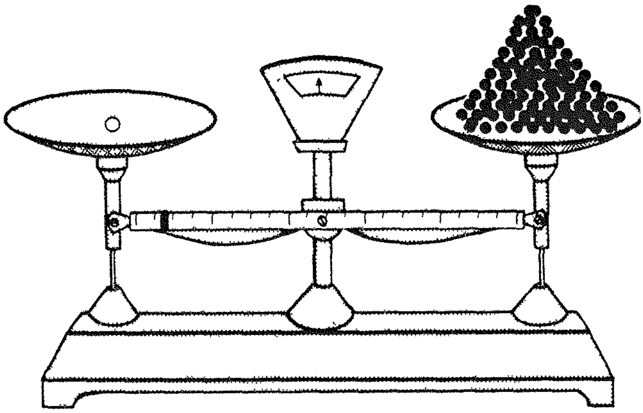
The electric charge of the proton and that of the electron are of equal magnitude, but a proton is much heavier than an electron. A proton weighs the same as 1836 electrons, and has almost the same mass as a hydrogen atom. A hydrogen atom is made up of one proton and one electron. Since the electron is very light, the mass of the proton is almost the same as that of the hydrogen atom.

James Chadwick

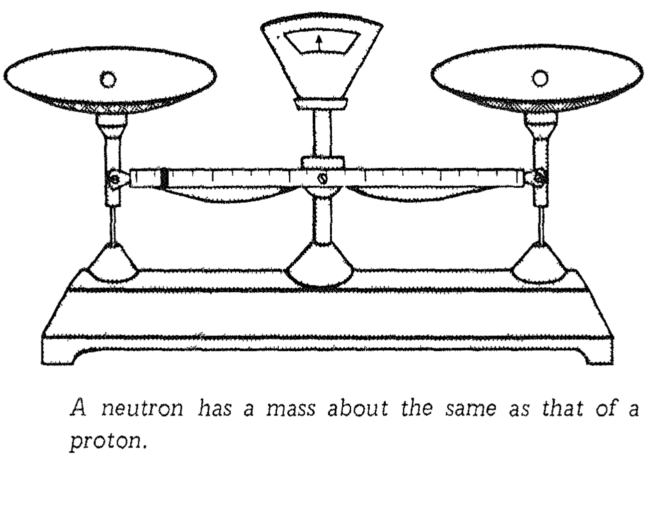
Neutrons

For many years it was thought that, like the hydrogen atom, all atoms were made of electrons and protons. This idea ran into all sorts of troubles but no one knew what to do about it. Then, in 1932, the English physicist James Chadwick found a neutral building block (or neutral particle); that is, a particle with no electrical charge. But its mass is about the same as that of the proton. Because the particle is neutral it is called the *neutron.*

Before the discovery of the neutron, scientists thought that, since the mass of the electron is so small, almost all the mass of the atom was provided by the protons. But we now know that both protons and neutrons contribute to the atom's mass. *The mass of the atom is roughly the sum of the masses of the protons and neutrons it contains.*



One proton balances 1836 electrons



A neutron has a mass about the same as that of a proton.

MASS NUMBER AND ATOMIC NUMBER

We know that the neutron has about the same mass as the proton, and each of these about the same mass as a hydrogen atom. If an atom contains 13 protons and 14 neutrons, its mass should be about 27 times the mass of a hydrogen atom. But the atomic weight of an atom is approximately how many times heavier it is than a hydrogen atom. So, 27 should be about the same as the atomic weight (or mass).

For this reason, *the sum of the number of protons and neutrons in an atom is called its mass number. The number of protons (or electrons) in an atom is called the atomic number. The difference between the mass number and the atomic number is the number of neutrons in the atom.*

The example we have just given refers to an atom of aluminum. It has 13 protons, 14 neutrons, and 13 electrons. So the mass number of aluminum is 27 and its atomic number is 13. The atomic weight of aluminum is 27, as seen in the table on page 12.

Are the electrons, protons, and neutrons in an atom arranged in some orderly way? Yes, the atom has a definite structure. To understand how the structure of the atom was determined, we must now consider the subject of radioactivity.

WHAT ARE RADIOACTIVE ELEMENTS?

Around 1900, scientists discovered that certain elements gave off invisible rays. These atoms are said to be *radioactive,* which means that they are active in giving off (or emitting) rays (or radiations). Two well-known radioactive elements are uranium, which we will discuss later, and radium. These elements have high atomic masses, that is, they have heavy atoms.

Three kinds of rays—alpha, beta, and gamma—are given off by different radioactive atoms. (Alpha, beta, and gamma are the first three letters of the Greek alphabet.) Do all radioactive atoms produce all three kinds of rays? No. Nearly all of them give off either alpha *or* beta rays, but not both. Sometimes gamma rays are given off as well. Radium, for example, emits alpha and gamma rays.

Since these rays are invisible, how do we know anything about them? They produce certain effects and these can be detected with instruments.

WHAT CAN WE LEARN FROM ALPHA PARTICLES?

Alpha rays are made of small particles called *alpha particles.* An alpha particle is a positively charged particle emitted by certain radioactive materials. It is made up of two neutrons and two protons bound together; therefore it is identical with the nucleus of a helium atom.

Suppose we take a sheet of paper and shoot rifle pellets at it. What will happen? Of course, the pellets will go right through the paper. Wouldn't you be surprised if some of the pellets didn't go through but bounced back toward you when they hit the paper?

This is what happened in early experiments in which alpha particles from a radioactive element were shot at a very thin sheet of metal. These experiments were conducted in the laboratory of Ernest Rutherford, a British physicist. Most of the alpha particles went through the sheet, but a few didn't go through but bounced right back. What did this mean?

THE ATOM HAS A NUCLEUS

In 1911, Rutherford concluded that atoms are not solid. He based his conclusion on the results obtained from the experiments mentioned on preceding page. In the center there is a very small core (or kernel), which he called the *nucleus* of the atom. This nucleus has a positive charge of electricity and carries nearly all the mass of the atom. Protons and neutrons make up the nucleus.

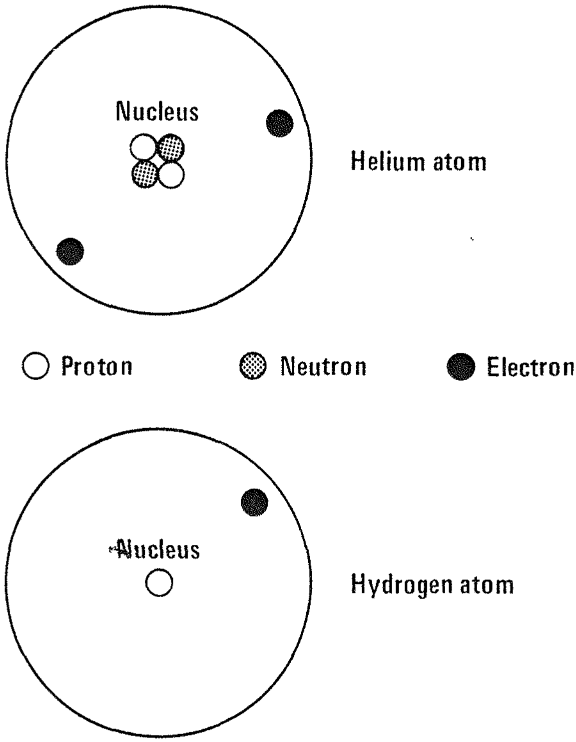
If the protons and neutrons are in the nucleus, where are the electrons? These particles, with their negative electric charge, are required to balance the positive charge of the protons. Electrons move in a sort of cloud around and outside the nucleus. Because they are so light, the electrons contribute very little to the mass of the atom.

All atoms have a small central nucleus, which has a positive charge. It is made up of protons and neutrons, and so contains most of the mass of the atom. Around the nucleus is a cloud of electrons, each with a negative electrical charge but very little mass. (See the diagram on the next page.)

Now let us see if this model of the atom explains what happens when alpha particles are shot at a thin sheet of metal.

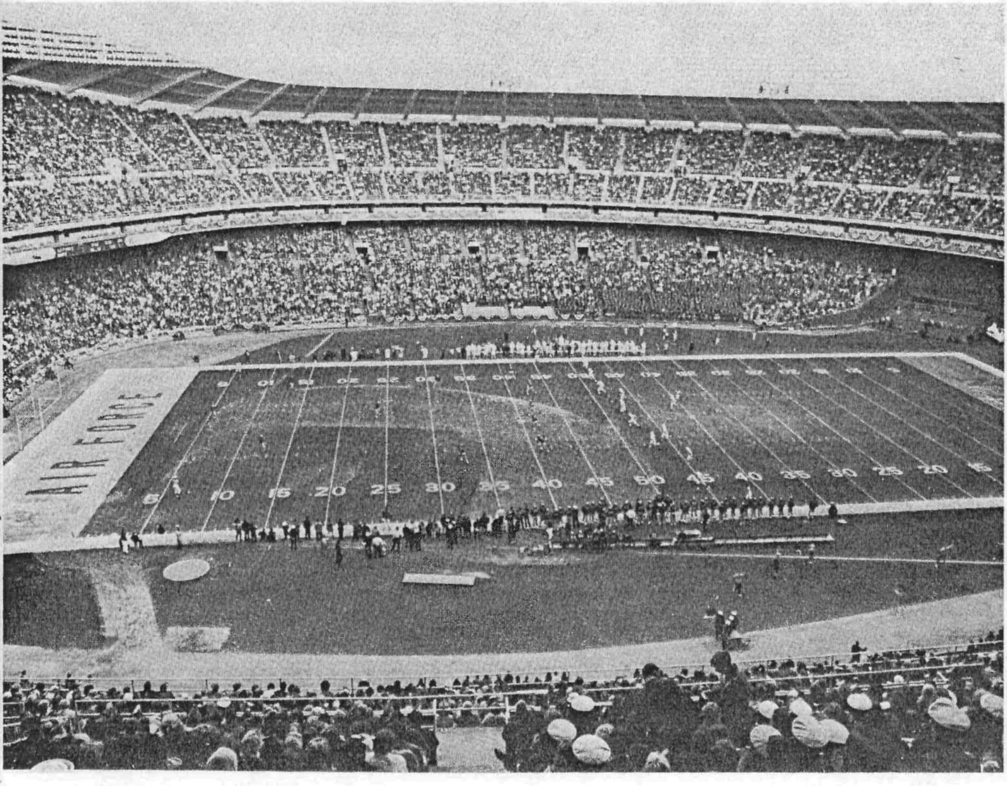
Because the *nuclei* (plural of nucleus) in the atoms of the metal are very small, most of the alpha particles, which are fairly heavy, will pass right through the electron cloud. But

once in awhile, an alpha particle passes close to a nucleus. The positively charged nucleus then pushes away (or repels) the positively charged alpha particle. As a result, the alpha particle will fly back in the direction from which it came.



HOW BIG IS A NUCLEUS?

The nucleus of an atom is very small. How does its size compare with the size of the whole atom? The size of a nucleus depends on its mass, but the diameter of an atom is about 10,000 times greater than that of its nucleus. *Imagine an atom magnified until its diameter is as long as a football field. The nucleus would then occupy less than a half inch at the center of the field.* Thus an atom is mostly "empty" space occupied by the moving electrons.



If an atom has so much empty space, how can atoms make up solids like concrete, wood, iron, and so on? The reason is that the cloud of electrons of one atom cannot penetrate the cloud of another atom. This can be compared with a propeller or a fan. When the blades of an electric fan or an airplane propeller rotate they use more space than they would when they are turned off.

WHAT ARE ISOTOPES?

All the atoms of an element have the same number of protons in their nucleus and the same number of electrons in the surrounding cloud, but some have different numbers of neutrons.

An isotope is one of two or more atoms with the same atomic number (the same chemical element) but with different atomic weights. The nuclei of isotopes have the same number of protons but different numbers of neutrons.

As an example, let us use oxygen whose atoms are present in air, water, and many minerals. Oxygen has three isotopes. The atomic number of oxygen is 8. All the isotopes of oxygen have the same number of protons and electrons. Each has 8 protons and 8 electrons. However, the number of neutrons in each isotope varies. One isotope of oxygen has 8 neutrons, one has 9 neutrons, and another has 10 neutrons. If you add the number of neutrons of each isotope to the number of protons you get the mass number.

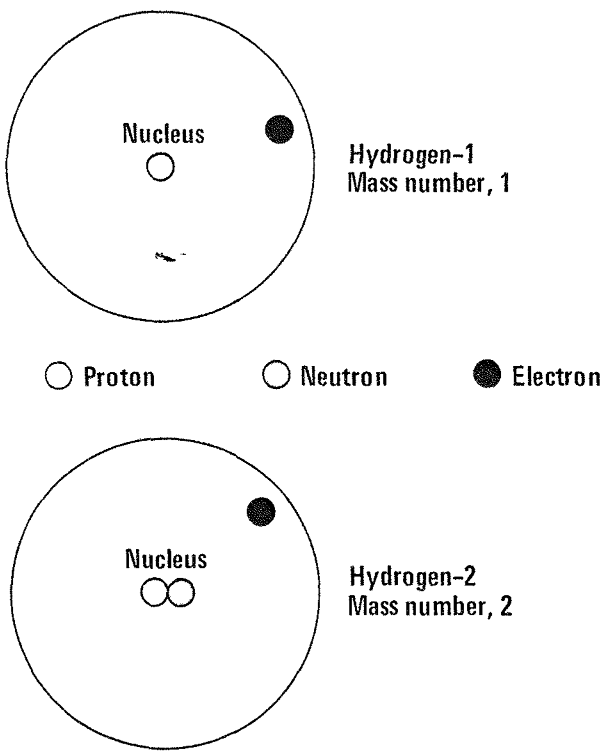
Protons	8	8	8
Neutrons	8	9	10
Mass number	16	17	18

Nearly all oxygen atoms have an atomic mass of 16. A few have mass numbers of 17 or 18.

Take a breath of air. Most of the oxygen atoms in your lungs will have a mass of 16. Some have an atomic mass of 18 and a very

small fraction have a mass of 17 atomic units. But your body will not be able to tell that the masses of the atoms are different.

About 70 of the 90 elements on earth are present as mixtures of two, three, or more isotopes. The element tin, for instance, has as many as 10 isotopes. In every case, what distinguishes one isotope from another one of the same element is the number of neutrons in the atomic nucleus. The mass number is used to identify an isotope: oxygen-16, oxygen-17, and oxygen-18, carbon-12 and carbon-13, uranium-235 and uranium-238, etc.



Both these isotopes have an atomic number of 1.

Here is how the scientist writes this notation using scientific shorthand:

$^{16}_{8}O$ $^{17}_{8}O$ $^{18}_{8}O$

mass number
symbol of element oxygen
atomic number

In the following table we have listed the atomic numbers and the mass numbers of the isotopes of some common elements. These are the same elements whose atomic weights we gave in the table on page 12. How many neutrons are in the atoms of each of these isotopes?

TABLE OF STABLE ISOTOPES OF SOME IMPORTANT ELEMENTS

Element	Atomic number	Mass number of isotopes*
Aluminum	13	**27**
Calcium	20	**40**, 42, 43, 44, 46, 48
Carbon	6	**12**, 13
Hydrogen	1	**1**, 2
Iron	26	54, **56**, 57, 58
Mercury	80	196, 198, 199, 200, 201, **202**, 204
Nitrogen	7	**14**, 15
Oxygen	8	**16**, 17, 18
Silver	47	**107**, 109
Sulfur	16	**32**, 33, 34, 36

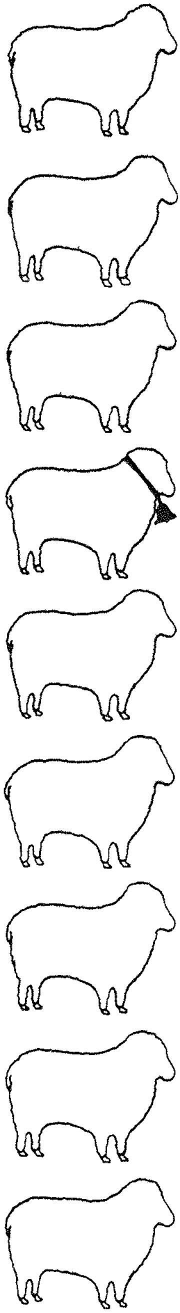
*Isotopes set in bold type are the most common forms of each element.

Notice that the atomic weights on page 10 are often the same as the mass numbers of the most common isotopes, but sometimes there are differences. This is because the atomic weights are really averages of the masses of the isotopes taking into account the proportions in which they are present in nature. For the same reason, atomic weights are usually not whole numbers as we saw earlier.

The isotopes of the elements with the highest atomic weight are all radioactive. In nature, nearly all the isotopes of the elements with mass numbers of 205 or less are not radioactive. They are called *stable isotopes* to distinguish them from the unstable (or radioactive) isotopes. Radioactive isotopes are commonly called *radioisotopes.*

It is possible to make radioisotopes of normally stable elements. For example, in addition to the three stable isotopes of oxygen mentioned before, five radioisotopes have been created. The atoms of these isotopes all have 8 protons in their nuclei, and so they are all oxygen. But the numbers of neutrons in the different isotopes are 5, 6, 7, 11 and 12. The mass numbers are therefore 13, 14, 15, 19, and 20. Scientists have made radioisotopes of all the elements. We will say something later about how this is done.

The atoms of radioisotopes have the same general properties that the nonradioactive (or stable) atoms of the same element have except that they emit radiations. The human body, for example, contains the element carbon as part of various compounds. Atoms of radioactive carbon-14 behave chemically in the same way in the body as do the stable atoms of the common isotope carbon-12.



RADIOISOTOPE USES

Sugar is a compound of carbon, oxygen, and hydrogen. Suppose you ate some sugar in which part of the carbon was present as the radioisotope carbon-14. Your body could not tell the difference between the radioactive and nonradioactive atoms in the sugar. Whatever happens to the ordinary sugar in your body would also happen to the radioactive sugar. With the aid of an instrument that can detect the beta rays given off by the radioactive carbon atoms, it would be possible to locate these atoms. Then we know that the nonradioactive carbon atoms in ordinary sugar must be at the same place.

The atoms of a radioisotope can thus serve as *labels* for compounds containing stable atoms. Such labels are particularly useful for several reasons. The rays they give off can usually be detected outside the body, and it is not necessary to place instruments, called detectors, within the body. Also, because the detectors are so sensitive, only an extremely small amount of a radioisotope need be used as the label.

When used as a label for a particular element, the radioisotope is called a *tracer*. It can be used to trace (or follow) the movements of the element. To understand this particular use of radioisotopes, you might think of atoms as a flock of sheep that always stay together. A blind shepherd could not tell where the sheep are. But if one of the sheep

had a bell around its neck, the shepherd would know the location of the whole flock by listening to the bell.

Medical Uses

Many hundreds of uses have been found for radioisotopes as tracers and for other purposes in medicine and industry. Several of these are described in companion booklets and so only a few examples will be given here.

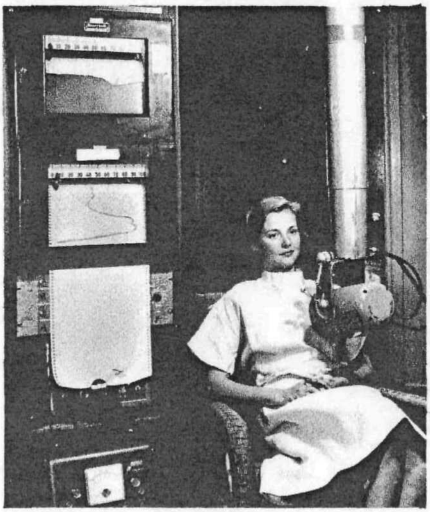
Suppose a patient is suffering from poor blood circulation because somewhere in his body there is a partial block that holds up the flow of blood. How can a doctor discover this block? Does he have to operate on the patient and look for the blockage? No, he can use a radioisotope tracer.

Common salt is sodium chloride, which is a compound of the elements sodium and chlorine. The sodium in ordinary salt is the stable isotope sodium-23. It is possible, however, for man to make the radioisotope sodium-24 and to form sodium chloride containing this isotope.

A doctor can take a weak solution of salt water and add to it a tiny amount of the radioactive sodium chloride. He then injects some of the salt solution into the man's blood through a vein in his arm. Ordinarily the doctor wouldn't be able to tell where the sodium chloride is in the man's body. But with the radioactive sodium-24 as a label, he

can use a radiation detector to find the location of the salt.

If the man's circulation is normal the radioactive sodium injected into his arm will soon be detected in his feet. But if there is some kind of block, the blood containing the sodium chloride will be held up at this point. By moving the detector over the man's body, the doctor can find exactly where the block is located.



Blood flow study using albumin that has been labeled with iodine-131.

Industrial Uses

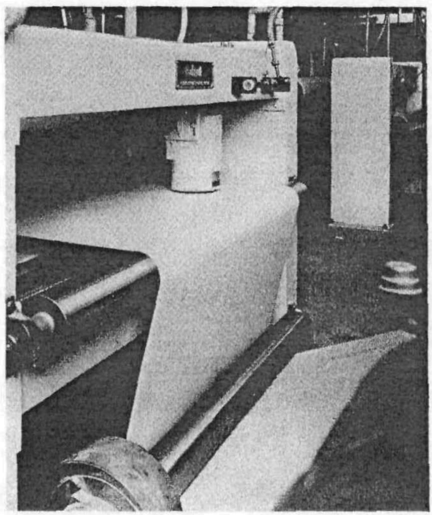
In addition to the use of radioisotopes as tracers, many uses can be found for the radiations that they give off.

Suppose you are running a factory that is producing thin sheets of paper, rubber, plastic, or other material. The machine making the sheets operates continuously. You want

to be sure that the sheets always have the same thickness.

How can you make certain that the thickness does not change? You don't have to stop the machine every few minutes to measure the thickness of the sheet. You can use the rays from a radioisotope.

A small piece of radioactive material is placed under the continuous sheet. Just above the sheet there is a detecting instrument.



Radioisotope thickness gauge used in a rubber factory.

Some of the rays from the radioisotope are absorbed by the rubber sheet, but a certain proportion will get through to the detector. The amount that will get through depends on the thickness of the sheet. As long as the sheet passing by the instrument has the same thickness, the signal will remain the same. But if there is a change of thickness the detector

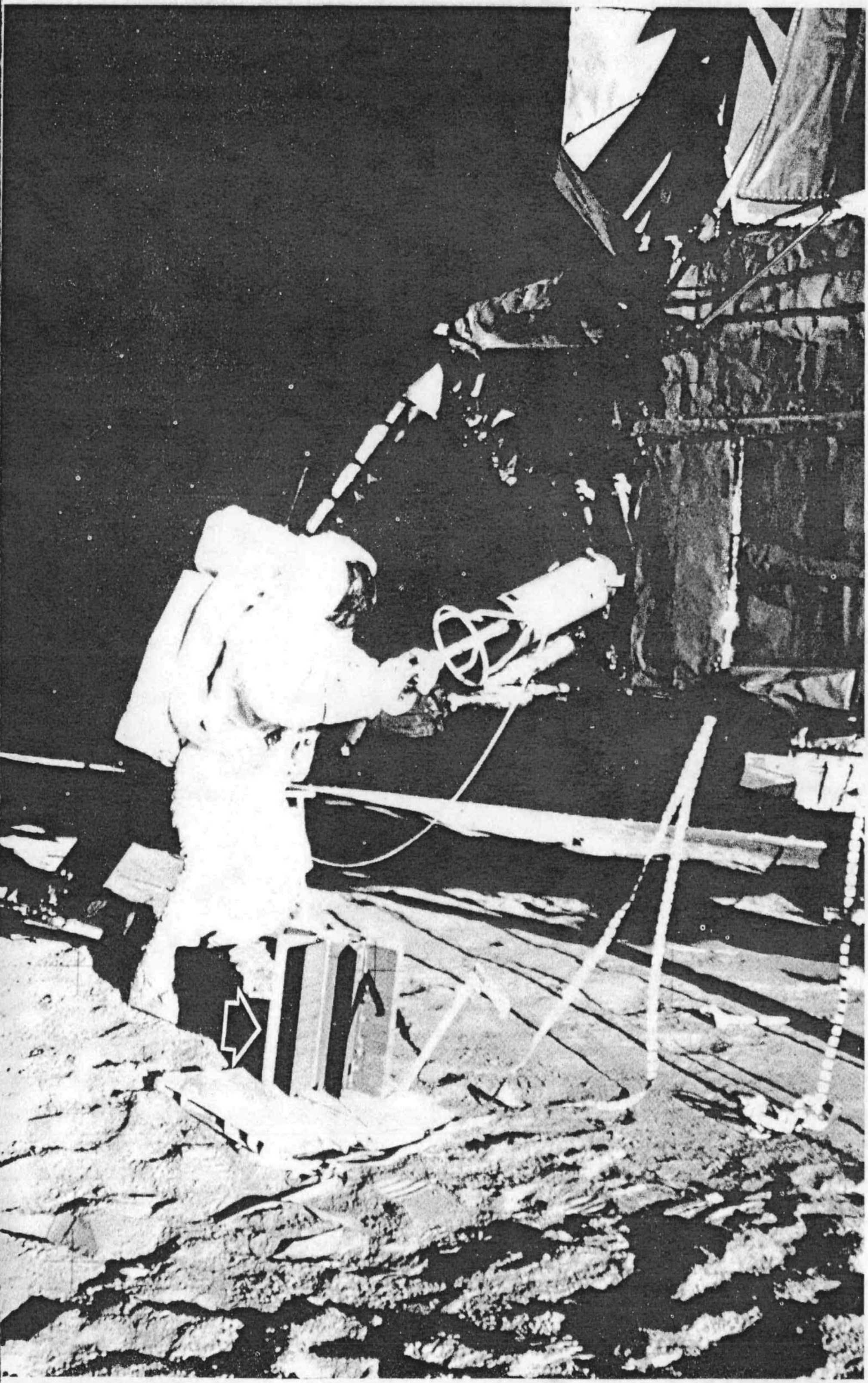
will sense it immediately, and the signal will change. Such a change can be made to adjust the machine automatically to insure the proper thickness.

Oil companies often pump oil long distances through pipelines from the oil wells to the refinery. Different batches of oil are often sent one after another, along the same pipeline. When the oil reaches its destination, how does the oil company know where one batch of oil ends and the other begins? A small quantity of a radioisotope can be added to the oil when a new batch is introduced into the pipeline. Instruments can then tell exactly where the new batch begins by detecting the radiations from the radioisotopes.

Electrical Power Uses

Radioisotopes can also be used as a source of heat. When the radiations are absorbed, their energy is changed into heat. The heat energy can then be turned into electricity. Compact radioisotope electrical generators of this kind have no moving parts and can operate unattended for several years. They have been used to provide power for remote weather stations near the North Pole, for lighthouses and other aids to ships at sea, and

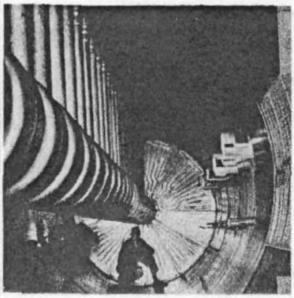
The SNAP-27 thermoelectric generator (arrow) provides approximately 73 watts of power for instruments left on the moon by the Apollo-12 astronauts. The power is generated by converting heat from the radioactive decay of plutonium-238 into electricity through a thermoelectric process. Astronaut Gordon Bean is removing the plutonium-238 from its container before inserting it into the generator.



for equipment on the U. S. Navy's Transit satellites. The Apollo astronauts have also left them on the surface of the moon to operate scientific instruments and radio sets.

HOW CAN NUCLEI ACT UPON EACH OTHER?

When the nuclei of two atoms (which may be of the same or a different element) approach each other, the positive electrical charges produce a repelling force. The two nuclei are thus kept apart. This is the reason why alpha particles, which are actually helium nuclei, sometimes bounce back when they are shot at a very thin sheet of metal.



Interior of a linear accelerator at the Lawrence Berkeley Laboratory in California.

Suppose one nucleus is accelerated (or speeded up) by using a special machine known as an *accelerator*. This nucleus is called a *projectile* particle in this case, because it is like a bullet being shot from a gun. The projectile can then be shot at another nucleus, called the *target* nucleus. If the speed (or energy) of the projectile particle is great enough to overcome the repelling force of the positive charges, the nuclei may then come close enough to interact with (or act upon) each other. This is called a *nuclear reaction*. As a result of a nuclear reaction two different nuclei are often formed. Many of the man-made radioisotopes have been produced in this manner.

A simpler way to bring about a nuclear reaction is to use neutrons as the projectile

particles. Although neutrons are generally found in the nuclei of atoms, it is possible to obtain them outside the nucleus and they can be used to interact with atomic nuclei. Neutrons have a great advantage as projectiles: Because they do not have a positive charge, they are not repelled by the nucleus of an atom. So neutrons do not need to be accelerated before they will interact with nuclei. A large number of neutron reactions have been observed and many of them give rise to radioisotopes.

WHAT IS NUCLEAR FISSION?

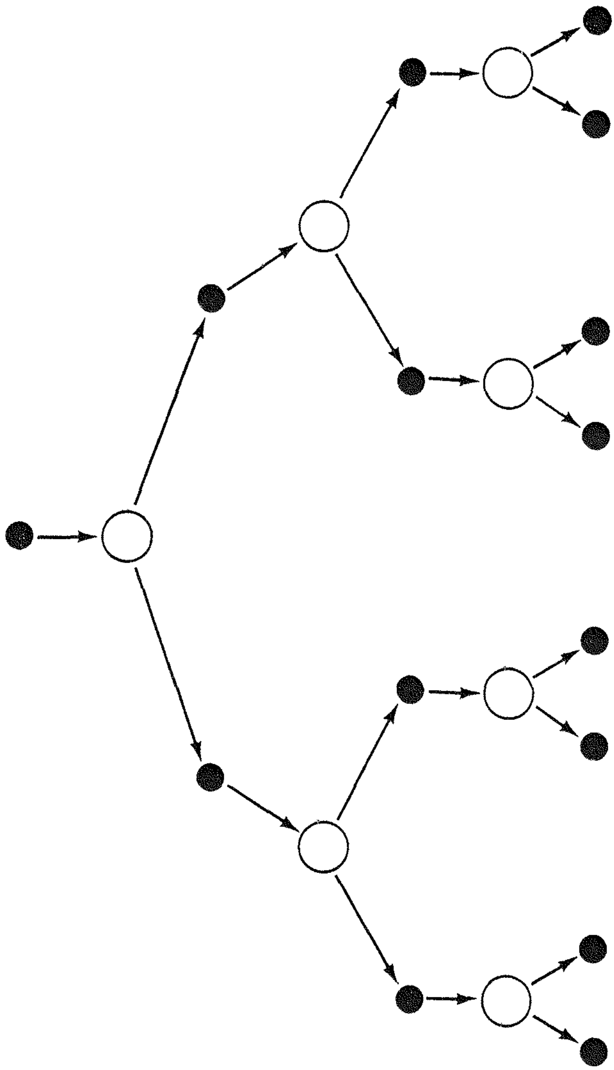
A neutron reaction of special interest is *nuclear fission.* This is very important because it made possible the atomic bomb that cut short the Second World War.

The word fission means to split into parts. Nuclear fission is a reaction in which a heavy nucleus is split into two lighter nuclei, each having about the same mass. There are many ways in which nuclear fission can be brought about. We are concerned only with the special one in which a neutron is absorbed by and splits the nucleus of a certain isotope of uranium.

As found in nature, uranium consists almost entirely of two isotopes, uranium-235 and uranium-238. The lighter isotope, uranium-235, is much rarer than the heavier one. It is the uranium-235 nucleus that fissions when it absorbs a neutron.

The Fission Chain

Why is fission of uranium-235 by neutrons so important? One reason is that when nuclear fission occurs a large amount of energy is released, and most of it appears in the form of heat. Another reason is that whenever a nucleus of uranium-235 splits by capturing a neutron, two or three other neutrons are set free. These neutrons can then cause other uranium-235 nuclei to fission, and then more neutrons are set free. Such a series of nuclear fissions is called a *fission chain*



Nuclear Fission of Uranium: A neutron hits the nucleus of an atom of uranium. The neutron splits the nucleus into two parts and creates huge amounts of energy in the form of heat. At the same time other neutrons are released from the splitting nucleus and these continue the fission process in a chain reaction.

reaction. Heat is generated in every individual fission of a nucleus. So a fission chain results in the continuous production of heat.

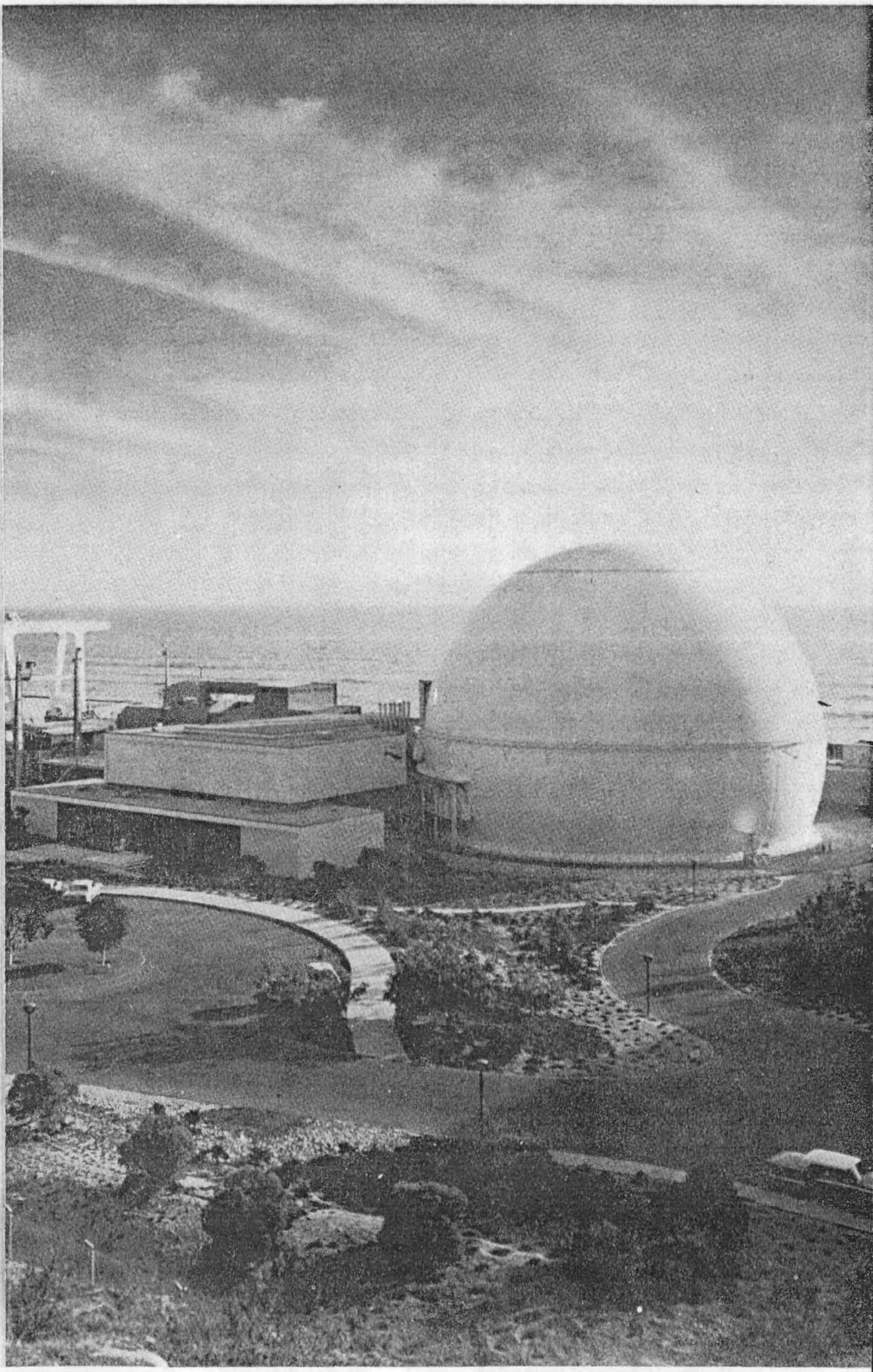
We might compare such a reaction with the following example.

Suppose a friend sent you a letter and in it a postage stamp was enclosed so that you could send a letter to another friend. In the letter you sent, you enclosed a postage stamp for your friend to send a letter to still another friend, and so on. A continuation of such letters, each with a stamp enclosed, would represent a chain of letters. The postage stamp is the means of maintaining the chain. The neutrons in fission are like the postage stamps: They are the means whereby the fission chain is kept going.

We have seen that only one postage stamp (or one neutron) is needed at each stage for the chain to be maintained. Suppose that instead of one stamp, you sent two stamps for each friend to write letters to two friends, and you enclosed two stamps in each case. The number of letters would double at each stage of the chain. There would be 2, then 4, then 8, then 16, then 32 and so on. The number of letters would increase at a fast rate. The same is true of a neutron chain. Only one neutron is needed at each stage, but if more than one is available, the number of neutrons—and of fissions—goes up very rapidly.

Of course a letter will usually take a day or two to be delivered. But neutrons travel very fast. The time between the release of a

neutron by a fissioning nucleus of uranium-235 and its capture by another such nucleus is actually a very small fraction of a second. You can therefore see why the number of neutrons in a chain can go up very quickly.



NUCLEAR REACTORS USE FISSION

In a machine called a *nuclear reactor* a fission chain with neutrons is allowed to proceed under careful control in uranium fuel. Each fission produces, on the average, about 2.5 new neutrons. Some fissions yield only one neutron; others five or more. At least one of the 2.5 neutrons *must* go on to create more fissions if the chain reaction is to be sustained. The other 1.5 or fewer neutrons either escape from the uranium fuel or are absorbed in the fuel (without causing fission) and in the control material.

Remember that most of the energy of fission appears as heat. Consequently, a great deal of heat is produced in a nuclear reactor. A nuclear reactor is therefore like a furnace. But instead of burning coal, oil, or gas, the reactor uses uranium-235 as the fuel. Ordinary fuels require oxygen from the air to permit them to burn, but the nuclear fuel uranium-235 does not need oxygen. Since the heat energy produced in a reactor arises from the fission of atomic nuclei, it is often called *atomic energy* or *nuclear energy.*

◀ *The San Onofre Nuclear Generating Station near San Clemente, California, has a net electrical capacity of 430,000 kilowatts and began commercial operation in 1967.*

NUCLEAR ENERGY PROVIDES USEFUL POWER

In most electric power stations coal, gas, or oil is burned and the heat is used to boil water and turn it into steam. The steam then operates a generator that produces electricity. The only obvious difference in a nuclear power station is that heat released by fission

One truckload of uranium fuel can supply the total electrical power needs of a city of 200,000 people for one year.

in a reactor is used to produce the steam. The electricity is then generated in the usual way.

A closer examination would show that in the ordinary power station large quantities of fuel are brought in continuously. A good sized electric power station might use 1500 tons of coal, that is, about 30 railroad carloads, or as much as 300,000 gallons of oil every day. But in a nuclear power station about a pound of fissionable material would produce the same amount of heat if all the

nuclei could be made to fission. Nuclear fuel may thus be thought of as a very powerful fuel, and this is one of its great advantages.

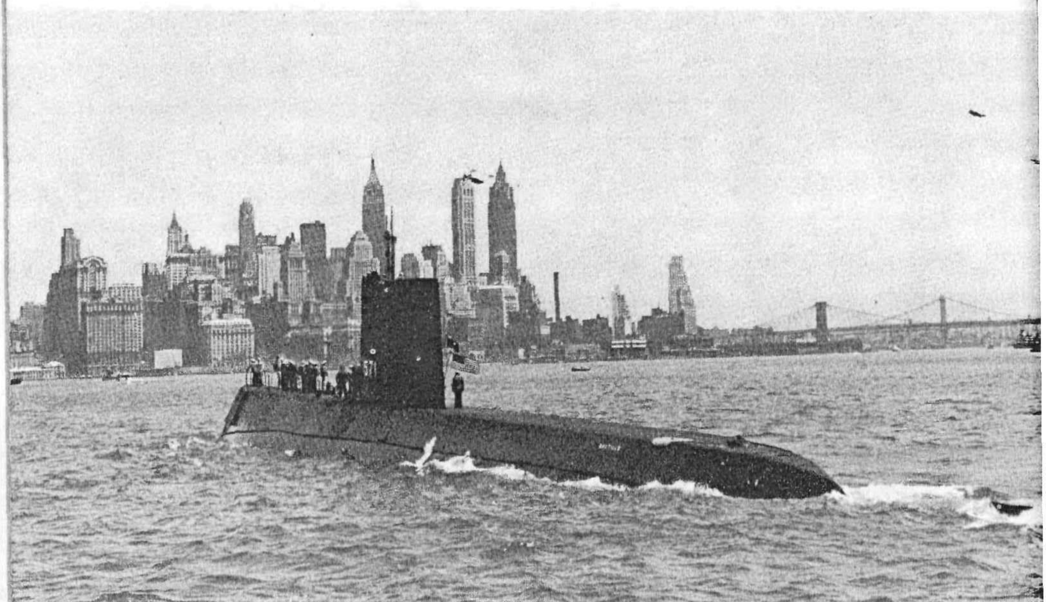
You will recall that the uranium-235 isotope, which is fissioned in a reactor, is the rarer of the two main isotopes of uranium. The most common isotope, uranium-238, cannot be used to maintain a fission chain. But by allowing the uranium-238 to take up some of the spare neutrons in a reactor, it will eventually be changed into the isotope of another element, plutonium-239. This isotope can be fissioned by neutrons just like uranium-235 and can be used to produce heat in a reactor.

By absorbing neutrons, the common isotope thorium-232 can be changed, in a similar way, to form uranium-233. This isotope can also be used to sustain a neutron fission chain. Thus, scientists and engineers hope to be able to make use of most of the uranium and thorium in nature for the release of nuclear energy and the production of electric power.

In several parts of the United States, as well as in other countries, nuclear reactor plants are already supplying electricity for use in homes and factories. In the future the supplies of coal, oil, and gas will grow smaller and their cost will go up. Then more and more electricity will be obtained from nuclear fission. Thus, uranium and thorium will be the fuels of the future. Because so little is needed to create heat and because some of it

can create other fuel, the supplies should be ample for a long, long time.

In addition to generating electric power, the heat produced in nuclear reactors is used to drive ships and submarines. A submarine driven by nuclear power can remain under water for a long time. It does not have to surface often to get oxygen to burn its fuel. In a few years' time, nuclear reactors may be used in rockets to take space ships to the planets.



The submarine USS Nautilus, *the world's first nuclear powered ship, enters the harbor of New York City.*

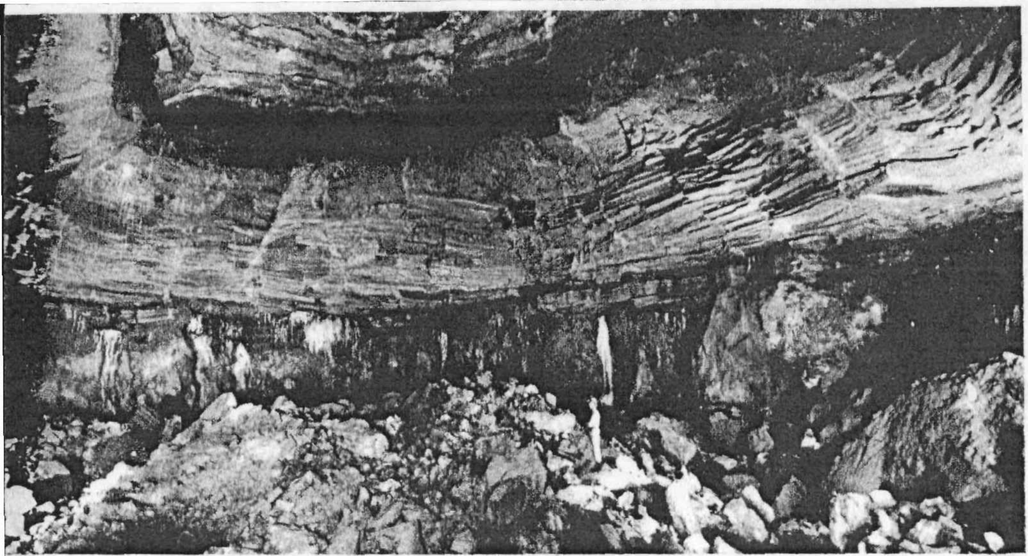
FISSION IS USED IN NUCLEAR BOMBS

At the beginning of this booklet we said that the same power is used both in the atomic bomb and in the production of electricity. How is this possible? The atomic bomb and the nuclear reactor both use fission but under quite different conditions. In the reactor the fission chain is kept under careful control, but in the atomic bomb the chain is allowed to go completely out of control. In the atomic bomb exact timing and other special conditions are required for an explosion to take place. These conditions cannot occur in a nuclear power reactor, and so there is no danger that such a reactor would ever explode.

When an atomic bomb is "fired", more and more neutrons are released in the uncontrolled chain reaction. These neutrons produce more and more fissions. Because there are so many nuclei of uranium-235 and plutonium-239 undergoing fission, very large amounts of heat are released in a very short time. The extremely high temperatures cause the bomb materials to turn into vapor. Tremendous pressures are developed and as a result there is a powerful explosion. This is the principle of the atomic (or fission) bomb.

You may have heard of another kind of nuclear bomb called the "hydrogen bomb". It is given this name because a fission bomb is used to trigger a reaction among the nuclei of isotopes of the element hydrogen. These

reactions can also produce a very large amount of heat that can cause an explosion.



This underground cavity 75 feet high and 135 to 196 feet across was formed by a peaceful nuclear explosion near Carlsbad, New Mexico.

PEACEFUL USES OF NUCLEAR EXPLOSIVES

Nuclear explosives may also be used for peaceful applications. They could help to build canals and harbors. Instead of using bulldozers and similar machines, the explosives would be buried underground and exploded. The explosions would throw out vast amounts of dirt and rocks and leave large craters. A line of such craters could be used to build a canal. Harbors for ships could be made in the same way in a rocky coast.

Underground nuclear explosions can also be used to break up rock formations. This would help gas and oil supplies flow more freely. Gas and oil that might otherwise be too difficult to get out of the ground could then be saved.

CONCLUSION

In this booklet we have taken a quick trip around the "world" of the atom. We have paid short visits to some of the "countries" in this world and we have met some of the "people" who live in it.

We hope that you have found the countries so interesting that you will want to visit them again. Perhaps you would want to spend more time in such countries as the nucleus, isotopes, radioactivity, fission, atomic energy, nuclear reactors, and others. We also hope that you would like to learn more about the inhabitants—electrons, protons, and neutrons—and about the work they do.

At the end of this booklet there is a list of books and motion pictures in which you can find out more about the atom. We hope that you will read and look at some of them. There are also other AEC booklets listed on the inside back cover of this booklet that will help you to understand why the atom is so important in our daily lives.

Scientists and engineers use the atom for the benefit of mankind. In addition, the study of the atom has provided us with a great deal of knowledge, and, in the words of the English philosopher Francis Bacon who thought and wrote about the atom nearly 400 years ago, "knowledge is power".

READING LIST

Basic Books

Atomic Energy, Matthew Gaines, Grosset and Dunlap, Inc., New York, 1970, 159 pp., $3.95. The peaceful uses of atomic energy in the U. S. and overseas are described. Grades 8-12.

Atompower, Joseph M. Dukert, Coward-McCann, Inc., New York, 1962, 127 pp., $3.95. Explains nuclear energy and how it is used. Atomic submarines and surface ships, reactors, nuclear space vehicles, peaceful atomic explosions, and radioisotope use in industry, medicine, and agriculture are described in words and pictures. Grades 5-8.

Atoms Today and Tomorrow (fourth edition), Margaret O. Hyde, McGraw-Hill Book Company, New York, 160 pp., $4.50. Describes applications of atomic energy in agriculture, industry, and medicine. Radioactivity and its control and the effect of bomb tests on the weather are also examined. Grades 7-11.

Basic Laws of Matter (revised edition), Harrie S. W. Massey and Arthur R. Quinton, Herald Books, Bronxville, N. Y., 1965, 178 pp., out of print. A nontechnical presentation of atoms and the laws governing their behavior. Grades 7-9.

The Fabulous Isotopes: What They Are and What They Do, Robin McKown, Holiday House, Inc., New York, 1962, 189 pp., $4.95. The theory of radioisotopes and how they are used in laboratories, hospitals, and on farms. Grades 7-10.

Inside the Atom (revised edition), Isaac Asimov, Abelard-Schuman, Ltd., New York, 1966, 197 pp., $4.95. This comprehensive, well-written text explains nuclear energy and its applications. Grades 7-10.

The New World of the Atom (revised edition), James Stokley, Ives Washburn, Inc., New York, 1970, 333 pp., $6.95. An in-depth description of atomic energy today. Grades 8-12.

Secret of the Mysterious Rays: The Discovery of Nuclear Energy, Vivian Grey, Basic Books, Inc., Publishers, New

York, 1966, 120 pp., $3.95. This outstanding history of nuclear research from Roentgen to Fermi is dramatically presented. The uncertainty of the unknown, the accidental discovery and the often lengthy and tedious research are woven into a fascinating tale. The international aspect of science is revealed in this story of scientists from around the world who pooled their knowledge and experience to unlock "the secrets of the mysterious rays". Grades 4-8.

The Story of Radioactivity, Colin A. Mawson, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1969, 64 pp., $4.50. The complete story of radioactivity—its history, uses, and potential. Grades 3-6.

The Useful Atom, William R. Anderson and Vernon Pizer, The World Publishing Company, New York, 1966, 185 pp., $5.95. An interesting and well-illustrated account of atomic energy from Democritus through the development of SNAP reactors. Anderson was captain of the first atomic submarine, the *Nautilus*. Grades 7-12.

Advanced Books

Anyone Can Understand the Atom, Henry Bentinck, Roy Publishers, Inc., New York, 1965, 134 pp., $4.50. This text, couched in a question and answer form, provides a simple explanation of nuclear energy and its applications.

The Atom and Its Nucleus, George Gamow, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1961, 153 pp., $1.95. A popular-level discussion of nuclear structure and the applications of nuclear energy.

Man and Atom: Shaping a New World Through Nuclear Technology, Glenn T. Seaborg and William R. Corliss, E. P. Dutton and Company, Inc., New York, 1971, 320 pp., $8.95. Provides a spectrum of the present and future uses of nuclear energy that can create a better world with cleaner cities, more productive agriculture, desalted seawater, etc.

MOTION PICTURES

Available for loan without charge from the Film Library, Office of Information Services, U. S. Atomic Energy Commission, Washington, D. C. 20545.

The Atom: Year of Purpose, 29 minutes, color, 1969. A description of 23 developments in the peaceful uses of the atom. Included are the Experimental Breeder Reactor No. 2, the Agro-Industrial Complex (nuclear reactors to desalt seawater for coastal desert agriculture and to produce electricity for factories), work on the National Accelerator Laboratory, peaceful nuclear explosives for large-scale excavation and natural gas stimulation, and a zonal centrifuge for ultra-pure vaccines.

Atomic Search, 29 minutes, color, 1970. Descriptions of important contributions to the peaceful uses of nuclear energy in 1969, such as an isotopic nuclear generator providing electrical power on weather satellites orbiting in space, development of an irradiated corrosion-resistant concrete polymer four times stronger than ordinary cement, development of an irradiated wood that is highly resistant to wear, a plowshare project for the stimulation of natural gas, and the positive identification of a new element.

The Mighty Atom, 27 minutes, color, 1968, Produced as part of the CBS News television series, "The 21st Century". This summary of the peaceful uses of atomic energy today and in the future touches on the need for nuclear power and the fact that it brings no air pollution; the nuclear merchant ship, the N.S. *Savannah,* nuclear propulsion for space rockets; SNAP (nuclear) generators which supply power for remote unmanned weather stations and off-shore oil rigs; use of the atom's energy to preserve foods by irradiation; nuclear medicine; the fight against cancer; nuclear-powered man-made hearts; the theory of atomic fission and the controlled nuclear reaction in a reactor; burial of atomic wastes; and the theory and operation of giant accelerators to smash atoms and study their subatomic particles.

A is for Atom, 15 minutes, color, 1964. This non-technical, fully animated film explains the structure of the atom using an analogy to the solar system, discusses natural elements and artificially produced elements and how they are identified by number, describes stable and unstable atoms, and tells of the discovery of nuclear fission. It explains how a chain reaction is produced, describes the principles of a nuclear reactor and its application for electrical power and propulsion, and reviews the many applications of atomic radiation in industry, biology, medicine, and agriculture.

Controlling Atomic Energy, 13½ minutes, color, 1961. This basic teaching film, based on a conversation between a science author and a young student, discusses radioactive atoms and what they are, detection and safety apparatus that is used in the safe handling of radioactivity, nuclear fission and chain reactions and the control of these reactions in nuclear reactors, production of electricity and propulsion from reactor fission, and the production of radioisotopes from reactors. The film ends with a discussion of the applications of nuclear energy in areas such as diagnosis and treatment of disease, food sterilization, biological applications, industrial uses, and production control.

Man and Radiation, 28½ minutes, color, 1963. This film discusses a wide spectrum of the uses and applications of radiation in medicine, industry, agriculture, power production, and research. After an animated sequence in which the origin of radiation is explained, complete with a historical presentation of its discovery, the film presents another animated sequence on the kinds and types of radiation.

Introducing Atoms and Nuclear Energy, 11 minutes, color, 1963. This film describes atomic structure, using models containing protons, neutrons, and electrons orbiting about the nucleus, and the origin of nuclear energy in the nucleus of unstable atoms, which may either lose or gain particles. The concepts of nuclear fission and chain reactions are introduced with models to illustrate the fission process.

Nuclear reactors and the production of electricity are illustrated

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The booklets are listed below by subject category

General Interest

WAS-009 Atomic Energy and Your World
WAS-002 A Bibliography of Basic Books on Atomic Energy
WAS-004 Computers
WAS-008 Electricity and Man
WAS-006 Nuclear Terms, A Glossary
WAS-013 Secrets of the Past Nuclear Energy Applications in Art and Archaeology

The Environment

WAS-414 Nature's Invisible Rays
WAS-204 Nuclear Power and the Environment

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WAS-105 The Genetic Effects of Radiation
WAS-107 Radioisotopes in Medicine
WAS-109 Your Body and Radiation

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WAS-404 Direct Conversion of Energy
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WAS-406 Lasers
WAS-407 Microstructure of Matter
WAS-411 Power from Radioisotopes

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WAS-303 The Atomic Fingerprint Neutron Activation Analysis
WAS-302 Cryogenics, The Uncommon Cold
WAS-306 Radioisotopes in Industry

Nuclear Reactors

WAS-502 Atomic Power Safety
WAS-513 Breeder Reactors
WAS-503 The First Reactor
WAS-505 Nuclear Power Plants
WAS-507 Nuclear Reactors
WAS-508 Radioactive Wastes

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